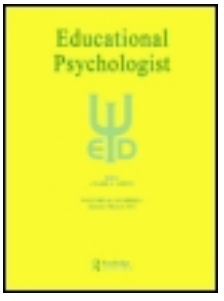
This article was downloaded by: [University of Illinois at Urbana-Champaign]
On: 31 May 2013, At: 12:18
Publisher: Routledge
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Educational Psychologist
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/hedp20

Rocky Roads to Transfer: Rethinking Mechanism of a Neglected Phenomenon

Gavriel Salomon & David N. Perkins

Published online: 08 Jun 2010.

To cite this article: Gavriel Salomon & David N. Perkins (1989): Rocky Roads to Transfer: Rethinking Mechanism of a Neglected Phenomenon, Educational Psychologist, 24:2, 113-142

To link to this article: http://dx.doi.org/10.1207/s15326985ep2402_1

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.tandfonline.com/page/terms-and-conditions

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

EDUCATIONAL PSYCHOLOGIST, *24*(2), 113–142
Copyright © 1989, Lawrence Erlbaum Associates, Inc.

Rocky Roads to Transfer: Rethinking Mechanisms of a Neglected Phenomenon

Gavriel Salomon
The University of Arizona

David N. Perkins
Harvard Graduate School of Education

Recent findings of transfer and nontransfer in such areas as planning and problem management skills, computer programming instruction, and literacy-related cognitive skills reveal paradoxes that invite explanation. In this article, we separate the "how" of transfer—the mechanisms that lead to it—from the "what" of transfer—the kind of knowledge and skill that might get transferred. We argue that transfer occurs in two ways. *Low-road transfer* depends on extensive, varied practice and occurs by the automatic triggering of well-learned behavior in a new context. *High-road transfer* occurs by intentional mindful abstraction of something from one context and application in a new context. Such transfer can either be of the *forward-reaching* kind, whereby one mindfully abstracts basic elements in anticipation for later application, or of the *backward-reaching* kind, where one faces a new situation and deliberately searches for relevant knowledge already acquired. Findings of transfer or nontransfer reflect whether the conditions for either low-road or high-road transfer were met. Qualitative predictions stemming from this theory of the mechanisms of transfer are offered and discussed.

Does the mathematical knowledge one acquires or the chess playing skills one learns and practices transfer to new instances, problems, and domains? Do changes in behavior, brought about by experience, therapy, or tutoring become manifested in new contexts and situations? If so, how? Questions about transfer like these are, of course, fairly old; in fact, they were among

Requests for reprints should be sent to Gavriel Salomon, Department of Communication, University of Arizona, Tucson, AZ 85721.

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

the first issues to be addressed by early psychologists such as Thorndike and Woodworth (1901).

The study of transfer as a central phenomenon in learning and behavior was extensively pursued in the past in an attempt to develop explicit theories of it. Then, for a while, it became embedded in more general cognitive theories that dealt with transfer indirectly by implication only. Thus, for example, one could deduce from an information processing perspective that transfer will probably depend on how a memory search is initiated, the kinds of memory nodes accessed, and the extent of their connectedness to other nodes in memory. Addressing transfer from the perspective of schema theory, one could suggest that transfer greatly depends on the activation of relevant anticipatory schemata. For instance, Johnson-Laird (1983) argued that "If subjects already possess a mental model of the relation expressed in the general rules, or a model that can be readily related to the rule, they are much more likely to have an insight into the [new] task" (p. 33). Recently, however, issues of transfer become explicit again in a variety of contexts, including such topics as the cultivation of intelligence (Nickerson, Perkins, & Smith, 1985), the training of learning strategies (Weinstein & Mayer, 1985), the study of how programming affects cognitive skills (e.g., Pea & Kurland, 1984), the development of symbolic capabilities (Gardner, 1983), the study of how inert knowledge can be made more useful in new contexts (Bransford, Franks, Vye, & Sherwood, 1986), and more.

These diverse contexts wherein transfer plays a role invite a broad-based explanatory perspective on transfer. Such a perspective is all the more needed because transfer-related findings in these areas are often difficult to interpret and puzzling in the light of contradictory findings. Consider the case of transfer in the study of programming. Although Papert (1980) spoke of LOGO as a source for the acquisition of generalizable thinking patterns and "powerful ideas," Pea and Kurland (1984) found no evidence of such as measured by transfer to planning tasks. On the other hand, Clements and Gullo (1984) reported rather impressive transfer results from LOGO. Similar difficulties arise in other areas in which transfer facilitating conditions have been set up, but little transfer has been observed (e.g., Bransford et al., 1986). We have to ask, what accounts for these discrepancies between expectations of transfer and findings? Are the theories wrong? Are the findings wrong? Or, do the findings not address quite the same cases as the theories? We return to some of these cases of conflicting results later and try to resolve them.

Such examples make it plain that basic questions of transfer simmer beneath the surface in numerous areas of psychological and educational inquiry. The phenomenon of transfer needs to be confronted head on by explicit attempts to explain it and its paradoxes. Accordingly, in what follows, we outline a tentative theory of the internal mechanisms of

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

transfer. In particular, we argue that transfer is not at all a unitary phenomenon. Rather, transfer can occur by different routes dependent on different mechanisms and combinations of mechanisms. To anticipate the arguments to be presented, we distinguish between two classes of routes, low-road transfer and high-road transfer. Low-road transfer primarily reflects extended practice; distance of transfer depends on amount of practice and the variability of contexts in which the practice has occurred. High-road transfer, on the other hand, depends on the mindful abstracting of knowledge from a context. We suggest that the high and low roads and their variants account for the conflicting results on transfer and allow qualitative predictions about the educational, cultural, and other conditions that foster transfer.

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

SOME KEY DISTINCTIONS

Before proceeding with our theory, there are three matters that need clarification. These are the distinction between transfer and mere learning, between *what* is transferred and *how* it is transferred, and between *amount* and *distance* of transfer.

Transfer Versus Mere Learning

Any learning involves transfer in at least a trivial sense: A person cannot be said to have learned something unless the person displays that learning on some other occasion, however similar. How, then, does one distinguish between trivial transfer and transfer in which there is a genuine "side effect" or "spill-over effect?" Roughly, when learning something leads to a later performance we identify as more or less the same in a context we identify as more or less the same, we do not call this transfer, we just call it learning. For instance, we usually do not imply that transfer is taking place when students supply for the test the dates they drilled themselves on in preparation; we think of the drill and the test as more or less the same. The students have simply learned the dates.

As a point of usage, this is clear enough, but as a point of definition, it is troublesome. When do we call two behaviors or contexts "the same"? Evidently, there is no hard criterion. We draw such lines according to our intuitions, which differ somewhat from person to person. Sometimes what one person calls transfer, perceiving the contexts in question as "different," another may call mere learning, perceiving the contexts in question as "the same." Moreover, there is a suspicious circularity involved. As Goodman (1978) pointed out, what transfers to what may itself be part of our tacit standards for similarity. For instance, perhaps we see the drill and the test

as the same not so much because of any striking similarity in general terms—after all, they are rather different in a number of respects—but because experience has taught us that the dates learned well during the drill will be recalled readily for the test.

In consequence, similarity judgments cannot be considered an independent criterion for distinguishing between trivial and nontrivial transfer. Neither similarity nor any other evident criterion draws a hard line between cases of mere learning and transfer. Rather, transfer is more likely to be mentioned when learning has a side effect we were not perfectly confident it would have. As to the theory of mechanisms of transfer offered here, it makes no effort either to reform or predict when people speak of transfer in the nontrivial sense.

What is Transferred?

Identifying a case of transfer requires no more than documenting the side effect of learning something on a different performance or context. However, claims about transfer ideally should and often do involve proposals on what was transferred. For instance, if one says that chess play improves mathematical reasoning because it teaches logic, one is making a claim not only *that* transfer occurs but about the *what* that is being transferred. In general, the *what* might be a "subroutine" developed in the learning context but also useful in the transfer context: an overarching principle abstracted in the learning context but applicable in the transfer context, a piece of factual knowledge useful in both but in quite different ways, a learning strategy that becomes used in new domains, a cognitive style, or even a complex strategy of approaching new problems. The possibilities are manifold, and the general notion of transfer is apparently indifferent to them.

We argue, however, that the *how* of transfer—the mechanisms employed—is not totally indifferent to the *whats* of transfer: One mechanism may be more appropriate for the transfer of explicit knowledge and strategies, whereas another mechanism may be so for more general abilities and clusters of strategies. The view of transfer described here concerns mainly the *how* of transfer and far less so its *whats.* However, because there is a possible relationship between the way transfer is attained and what is actually transferred, we are unable to avoid discussion of the *whats.*

How Much Transfer?

In considering how much transfer occurs, it is commonplace to distinguish between *amount* and *distance* of transfer. Transfer from A to B involves more distance to the extent that B is more remote or novel with respect to

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

A. Transfer from A to B involves a greater amount of transfer to the extent that the A learning makes a bigger difference to B performance. Measuring amount of transfer presents merely the technical problem of measuring gains on B resulting from A learning. Measuring distance of transfer, in contrast, calls for a "dissimilarity" or "novelty" metric of a nonobvious nature, a metric that may not even exist. Moreover, the notion of distance of transfer involves the philosophical dilemma mentioned earlier about judgments of sameness. Nonetheless, it is useful to speak loosely of distance of transfer, as long as we recognize the difficulties in formalizing the notion.

TWO KINDS OF TRANSFER

In the sections to come, we offer a fairly technical examination of the mechanisms of transfer proposed here. However, everyday examples provide the best introduction to the concepts. Consider, then, three stories of transfer that belong to the everyday world.

From Car to Truck

Suppose you have learned to drive a car. Then, on some occasion, you find you need to drive a truck but wonder whether you could. When you sit in the cab, however, your concerns dwindle. The setting seems strange, yet familiar. You do not have to do anything special; you simply drive as you always have. To be sure, it feels a little odd, but by and large it works fine. Of course, in certain circumstances you may be surprised. If you drive a trailer truck and try to back up, you will find that the trailer does not behave as you expect it to. Still, on the whole, the transition from car to truck is quite painless and automatic; your old skills only require some fine tuning to suit the context of truck driving.

From Study Hours to Steady Hours

In the sixth grade, you had a teacher who emphasized good study habits. This teacher encouraged all the students to organize their days to ensure that anything important got done. The teacher stressed one principle particularly: If you want to get something done, set aside a definite time for it and stick to that time. The teacher was interested mainly in study time, but she encouraged the students to apply the same principle to other activities, like piano practice time or lawn mowing time. You actually did schedule two or three activities that way. Now, years later, you lead a busy professional life. Your work involves a variety of small projects. Every time

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

a project becomes a special priority, it immediately occurs to you to set aside "protected time" for the project—say, first thing in the morning—so that progress on the priority project is assured, whatever else happens.

From Tantrums to Supermarket

When you were a child, you tended to lose your temper all too often to suit your parents. Finally, your mother drilled into you a little strategy: Count to 10. She pressed the point so often that you actually learned to count to 10 when you felt yourself losing your temper; sometimes it even helped, although not always. Now you shop in the supermarket once a week, and you find that, just as supermarket owners hope, you are a confirmed impulse buyer. After a while, you get annoyed with yourself and wonder whether you can do anything to inhibit your impulsiveness. You could just try to hold back—but you doubt you have the will power. You could be sure to shop when you are not hungry—that might help, you think. Then the "count to 10" strategy occurs to you. You try it out and find that, just as in the old days, it does help sometimes.

Transfer appears in all three of these stories: Learning in one context enhances performance in a somewhat different context. Yet, in significant ways, the three stories differ. In the first episode, transfer occurs quite automatically; you simply drive the truck. In contrast, the second and third episodes share the feature of an explicitly known and applied principle—"set aside time" or "count to 10." The last two stories themselves display an interesting difference, however. In the "set aside time" story, the hero has learned a general principle thoroughly in youth and so applies it quite spontaneously to new situations later. The principle simply "pops up" on relevant occasions. However, in the "count to 10" story, nothing pops up. Rather, the hero formulates the problem of inhibiting impulsive shopping and actively searches for solutions, after a moment or two retrieving an inhibition strategy associated with quite a different context, controlling temper.

From these examples, we want to draw a major distinction and a minor one. The major distinction contrasts low-road with high-road mechanisms of transfer. The low-road mechanism involves the spontaneous, automatic transfer of highly practiced skills, with little need for reflective thinking. The "car to truck" story illustrates this sort of transfer. The high-road mechanism involves the explicit conscious formulation of abstraction in one situation that allows making a connection to another.

The second distinction develops a contrast between the "set aside time" and "count to 10" examples. By definition, both involve high-road transfer, with its role of consciously formulated abstractions. However, in the "set aside time" story, the principle is so well learned in the first place as a

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

general principle that it simply suggests itself appropriately on later occasions. That is, the general formulation occurs initially and finds new application spontaneously later. One might say that during the initial learning it became set up for later spontaneous use, and so we will speak of *forward-reaching* transfer.

In the other high-road story, the "count to 10" strategy originally is learned for the context-specific purpose of inhibiting tantrums. Later, deliberately abstracting the need for an inhibiting strategy in the supermarket situation, the hero retrieves the previously learned strategy as potentially applicable. Here, in other words, the deliberate formulation of an abstraction occurs not during original learning, but as the target activity is addressed. We call this *backward-reaching* high-road transfer, because the individual formulates an abstraction guiding his or her reaching back to past experience for relevant connections. It should be added that other combinations can happen as well; for example, someone might formulate conscious abstractions both during the original learning activity and the later application activity, as part of making a connection between the two. Nonetheless, for our purposes, the distinction between forward-reaching and backward-reaching high-road transfer will serve well enough to make the points that need to be made.

As quotidian as these stories of transfer are, they demonstrate distinctions that have not generally been recognized in the literature on transfer. As a trend, discussions of transfer have treated it as a unitary phenomenon, without differentiating alternative routes by which transfer might occur. To be sure, there have been important treatments of whether and under what conditions transfer happens. However, by and large, these treatments have not linked the question of conditions of transfer to the question of alternative *mechanisms* and their distinctive psychological demands. In contrast, we argue that it is exactly from the different mechanisms of transfer just outlined that different conditions emerge. There is more than one way for transfer to occur, more than one set of conditions that might be met, and, when transfer does not occur (as often happens), it fails because the circumstances do not meet any combination of conditions that fosters transfer. This perspective, we maintain, allows integrating the diverse and somewhat inconsistent findings on transfer under one model. Subsequent sections discuss in detail the low and high road mechanisms, after which several puzzling findings about transfer are examined in terms of the model.

THE MECHANISM OF LOW-ROAD TRANSFER

The central problem of mechanism in examining low- or high-road transfer is to explain how previously learned elements (subroutines, principles,

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

habits, etc.) can be (a) evoked and (b) successfully applied in a somewhat different situation. In the case of low-road transfer, we propose that the process works as follows. A cognitive element is learned and practiced in a variety of contexts until it becomes quite automatic and somewhat flexible because of the variety. On a later occasion in another context, the stimulus characteristics sufficiently resemble those of one of the earlier picture contexts to trigger automatically the element. The next context also resembles the earlier ones sufficiently so that the somewhat flexible element suits the new context. The "car to truck" example illustrates all these features. Car driving skills are practiced enough that they become highly automatic. When one needs to drive a truck, the appearance and feel of the cab triggers one's somewhat flexible car driving habits, which indeed are flexible enough to serve truck driving adequately. The key aspects of this process of low-road transfer are *varied practice* and practice to *automaticity*. We consider in turn the importance of each one of these.

Varied Practice

Practice that occurs in a variety of somewhat related and expanding contexts will force the cognitive element in question to adapt in subtle ways to each of these contexts, yielding an incrementally broadening ability that gradually becomes more and more detached from its original context and more and more evocable in others. Transfer aside, evidence for a gradual accumulation of a varied and flexible repertoire emerges plainly in the contemporary work on expertise (e.g., Chase & Simon, 1973; Chi, Glaser, & Rees, 1982).

This picture of low-road transfer as incremental extension also fits well a view of learning and memory described by Kolers and Roediger (1984; see also Hayes-Roth, 1977; Kolers, 1973, 1975). Kolers and Roediger argued from a wide base of evidence that learning largely reflects the particular information processing procedures exercised by an activity. Complexes of procedures previously exercised activate more readily and run off more efficiently, yielding the outcome of learning. Even seemingly minor contrasts in an activity can lead to the recruitment of a somewhat different set of procedures. Consequently, learning tends to be quite context bound and full of circumstantial links to the setting and occasion. Transfer occurs to the extent that a new circumstance calls on a complex of procedures overlapping a complex that was previously well-exercised. Varied practice would yield more transfer by exercising a wider variety of related complexes, thus making it more likely that a new circumstance would excite procedures many of which had worked together before.

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

Automatization

With the role of varied practice in focus, we now consider the contribution of automatization to low-road transfer. The extensive practice posited for low-road transfer naturally brings with it considerable automatization. Processing and, by extension, behavior, becomes fast, effortless, and unlimited by processing capacity. It is carried out in well-integrated "bundles" under stimulus control. It is thus automatic (Shiffrin & Schneider, 1977). In the absence of such practice, the same processing will be slow, effortful, capacity limited, and much more subject to intentional control. Such controlled processing facilitates long-term memory more than automatic processing (Fisk and Schneider, 1984) and enables one to reflect on constituent components and subroutines (Langer, 1985). Automaticity inhibits such analytic reflection (Kellog, 1982; Langer & Imber, 1979). In short, transfer by varied practice yields fringe benefits of efficiency while tending to inhibit high road transfer, which depends on conscious control and analytic awareness.

Moreover, automatization facilitates evocation of the elements transferred in low-road transfer when, indeed, as in the case of car driving, the activity receives extended practice. The automaticity of mastery, attained as a result of much repeated practice, short circuits the link between situation (e.g., wheel, car, and road) and behavior (e.g., truck driving). One's system automatically applies the learned behavior whenever it identifies situational cues it takes to be prototypical of a particular category of situations (Langer, 1985) or on the basis of shared cultural prescriptions. In consequence, a member of Western culture is likely to mindlessly commit the basic attribution error even in the face of visible situational factors (Ross, 1977), possibly due to the culture's customary way of perceiving individual behavior (J. G. Miller, 1984). Similarly, women's expectations for lesser social roles, absorbed from years of gender-specific socialization, are often automatically transferred even to new situations in which statuses are initially equal (Eagly, 1983).

Such transfer takes place precisely because it is automatic; behaviors and cognitions are stimulus-controlled. If one paused to analyze the new situation and search for a response appropriate to it, much less transfer might take place. Sometimes the situation is so critical that we are forced into mindful awareness of automatic transfer. Consider Americans trying to drive in England. Given familiar cues, their systems automatically take over and direct driving to the right—which in England is the wrong—side of the road. They have to be extremely mindful of the situation and attend to less prototypical and less overlearned cues to block the low-road (negative) transfer of right-side driving. The same problem occurs in other conditions

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

of driving, for instance, properly handling a skid or backing up a trailer truck, and in certain laboratory tasks, for instance, the Stroop Color–Word Test (Stroop, 1935).

Are Low- and High-Road Transfer Distinct?

A major concern about the mechanism outlined for low-road transfer might question its distinctiveness from high-road transfer on the grounds that the incremental extension process posited in effect yields abstractions like those of the high-road transfer. If a cognition or behavior comes to operate in a wide range of circumstances, this shows that it has in some sense become an abstraction, a general schema operative in many contexts.

We agree with this as far as it goes. However, not just abstraction, but mindful abstraction was defined as the crucial characteristic of high-road transfer (the nature of mindful abstraction is discussed shortly). As the examples illustrating high-road transfer showed, transfer via mindful abstraction can occur quite quickly in a way qualitatively very different from the low-road mechanism. No gradual process of incremental extension is entailed. In contrast, along the low road, a pattern of behavior or cognition becomes ever larger in its range of application by "stretching at the boundaries" so to speak, as repeated practice leads the learner to adapt to partially new cases in minor and largely unconscious ways. The resulting abstractions are representations that figure more in involuntary than in voluntary memory (Brown, 1975) and that may be inaccessible to intentional control and introspection (Kellog, 1982).

What Transfers by Way of the Low Road?

Earlier, we announced the intention to separate the issue of *how* transfer occurs from *what* gets transferred and mentioned the qualification that *what* interacts to a degree with the *how*. We conclude this technical examination of low-road transfer by focusing for a moment on this theme. What sorts of performances are likely to transfer by way of the low road rather than the high?

Broadly speaking, low-road transfer is the trend when a performance is unintentional, implicit, based on modeling and driven by reinforcement. This is typical of activities involved in such processes as socialization, acculturation, and experience-based cognitive development, resulting in the acquisition of habitual behavior patterns, response tendencies, personality traits, cognitive strategies and styles, expectations, belief systems, and the like. It is less typical with the application of principles and bits of knowledge acquired via direct and conceptually oriented instruction or social experience. The latter often afford reflective decomposition of

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

constituent behaviors or cognitions, offer a language in which abstractions can be encoded, and may actively reward explicit abstractions.

What happens if one tries to transfer such typically automatic matters as personality and cognitive style characteristics by way of the high road from a context in which one usually displays them to a context in which one usually does not? Immediately, a problem appears. One does not know just *what* one does to evince the behavior in question. The behavior has a kind of opacity, a resistance to analysis. Thus, low-road transfer remains the characteristic route. Two qualifications are in order, however. First of all, very analytical people with deliberate effort may well be able to articulate some of the elements involved in generally opaque behavior and achieve high-road transfer of those elements. Second, one can sometimes in a new context evoke a behavior holistically without analyzing it. For instance, one can sometimes deliberately put on a cheerful personality in the face of adversity without analyzing just what elemental behaviors constitute a cheerful personality. This is indeed high-road transfer, but not with an awareness of the structure of the behavior as is apparent in paradigmatic high-road transfer (e.g., transferring a strategy). Rather, here it is the control of evocation of the behavior that is transferred.

Qualitative Predictions

Recall that in an earlier section we distinguished between amount and distance of transfer. Amount refers to how much improvement (or, in the case of negative transfer, decrement) results in the transfer context from attaining some level of performance in the learning context. Distance concerns how far learning transfers and to which tasks: very similar ones, somewhat related ones, or even quite remote ones. The caveats about the vagueness and even circularity of distance should be remembered here. Nonetheless, the low road to transfer yields some simple predictions regarding the presence or absence of transfer and its amount and distance.

Extensive practice, typical of the low road, affects mainly *amount* of transfer because it leads to the automatic activation of whole "bundles" of interrelated responses (Hayes-Roth, 1977; Kolers & Roediger, 1984). Some new situations can activate such response clusters because of automatically detected similarity of prototypical cues (Schneider & Fisk, 1984). This is not likely for situations remote from the learning context, where what subtle or partial similarities there are would need intentional examination to detect. Nor would more practice make it more likely. Furthermore, because of the bundling, selective or partial application of specific skill components or fragments of knowledge is rare. Rather, low-road transfer involves automatic response generalization: Stimulus cues are automatically passed into working memory and acted upon (Hayes-Roth, 1977), for instance, when

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

experienced drivers have difficulties not attending to driving-related cues even when they are riding as passengers.

What can be said about more distant transfer via the low road? Some prospective low-road transfers include the cognitive ripple effects often expected from exposure to and mastery of symbolic forms, such as print as opposed to a culture of utterance (Olson, 1980), computer programming (Papert, 1980), televiewing (Salomon, 1979), and the like. For the most part, people attain mastery of these forms through extensive practice but without much of a push toward mindful abstraction created either by a teacher or the media.

There is indeed experimental evidence to show limited transfer effects with some of these symbolic forms—from television to paper-and-pencil spatial tests and from playing computer games to tests of inductive thinking (Greenfield, 1984). But none of the findings even comes close to the amount and distance of transfer effects often expected from mastery of symbolic forms. This should not surprise us, because large amounts of low-road transfer would only develop gradually over a long period of time. Hardly any short-range experiment, better suited to the study of high-road transfer, would reveal strong effects. On the other hand, socialization into a culture is likely to provide the prolonged practice that yields great amounts of low-road transfer (e.g., J. G. Miller, 1984). One would predict, therefore, that greater amounts of low-road transfer to related issues would take place from domains in which culture has a stronger socialization influence (e.g., the role of women in society, Eagly, 1983) than from domains of lesser cultural concern (e.g., the role of mountaineers in society).

THE MECHANISM OF HIGH-ROAD TRANSFER

We turn now to a closer look at the high road, our second road to transfer. The major difference between the low and the high roads to transfer lies in the processes that yield the transfer: automatic, stimulus-controlled, and extensively practiced behaviors or cognitions versus mindful deliberate processes that decontextualize the cognitive elements which are candidates for transfer. The hallmark of the high road is the *mindful abstraction* it involves. Let us briefly describe what we mean by abstraction, then mindfulness, and then—mindful abstraction.

Abstraction

We wish to distinguish here between abstraction as a product and a process. As a *product,* abstraction is intended here in its usual sense: An abstraction is a representation of some sort that is more general, less specified, than

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

another representation to which it is compared. For instance, the category furniture is more abstract than the category chair. Newton's law, F = mA, generalizes a whole range of particular interactions in the physical world, and the general algebraic expression, Strength = Resistive factor × Resultant factor subsumes a number of subordinate laws, like F = mA and E = RI (Ohm's law). For another sort of example, principles and strategies of thinking are abstract in that they generalize over diverse potential contexts of application. For instance, "seek control of key elements," relevant to chess play, war, and business, is a more abstract version of the well-known chess counsel, "seek control of the center," and, of course, generalizes analogous advice in other domains.

A *process* of abstraction is any process that achieves abstraction by a variety of information-processing maneuvers that can do so: Dropping details in a verbal description, "leveling" in a picture so that details are omitted but without an implication that the object lacks details (as in schematic profiles of airplanes, birds, animal footprints), substituting supercategories for categories, recategorizing elements in a more coarse-grained category system, "variabilizing" so that specified elements like color or length or domain are replaced by free-floating variables. It is not the aim of this discussion to enumerate the many ways abstraction can be attained or to present a full theory of abstraction. We simply note that abstraction should not be viewed as a special or rare human function; people achieve abstractions all the time.

Taking the process and product of abstraction together, abstraction involves the extraction from or identification in a learned unit of material, in a situation or in a behavior, some generic or basic qualities, attributes, or patterns of elements. These extracted qualities are represented in some internal symbolic manner (e.g., propositions) accessible to consciousness and, being devoid of contextual specifity, afford application to other instances. Abstraction thus involves both decontextualization and re-representation of the decontextualized information in a new, more general form, subsuming other cases. Abstractions, therefore, have the form of a rule, principle, label, schematic pattern, prototype, or category. This makes clear how abstraction leads to transfer: It yields a re-representation that subsumes a greater range of cases.

Mindfulness

By *mindfulness* we mean the volitional, metacognitively guided employment of nonautomatic ("controlled") processes (Salomon & Globerson, 1987) typical of "deeper processing" (Kintsch, 1977), of "greater cognitive capacity usage" (Kerr, 1973), of greater mental effort expenditure (e.g., Salomon, 1983), and of the "conscious manipulation of the elements of

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

one's environment" (Langer & Imber, 1979). When mindful processes are evoked, the individual inhibits or withholds the evocation of a first, salient response (Pascual-Leone, 1984), examines and elaborates situational cues and underlying meanings that are task relevant (Kane & Anderson, 1978), generates or defines alternative strategies (Pressley, 1986), gathers information necessary for the choices to be made (Bandura & Cervone, 1986), or draws new connections and constructs new structures (Langer, 1985). In these respects, the construct of mindfulness is very similar to Vygotsky's (1978) construct of "intellectualism."

Mindful Abstraction

The hallmark of the high roads—forward-reaching and backward-reaching transfer—is mindful abstraction. By this we mean the deliberate, usually metacognitively guided and effortful, decontextualization of a principle, main idea, strategy, or procedure, which then becomes a candidate for transfer; or, alternatively, the rarer case of learning of such a principle, idea, and so on, in abstract form in the first place. It should be noted that metacognitive guidance appears to play a major role here; in fact, some researchers see in the cultivation of metacognitive guidance the necessary, if not sufficient, condition for what we call here high-road transfer (e.g., Brown, Bransford, Ferrara, & Campione, 1983).

Why mindful abstraction? The reason for abstraction is plain: The abstract formulation provides the bridge from one context to the other. But why mindfulness? The reason is that: (a) the abstraction must be understood, and (b) the understanding requires mindfulness; automatic processes just do not yield novel abstractions that are well understood. Having an abstraction in the superficial sense of possessing a rote abstract representation without understanding it will not suffice. For transfer, the abstraction must be genuinely comprehended, not just learned as a formula. In particular, the person must grasp the relationship between the decontextualized representation and the "raw" instances of which it is an abstraction (e.g., Gick & Holyoak, 1987). Indeed, active learning wherein people achieve abstractions by themselves, although not necessarily producing better learning outcomes, facilitates farther transfer than so-called *passive reception* (Mayer & Greeno, 1972).

There appear to be numerous reasons for this difference, one of which may be that the processes called on during active learning are more learner than stimulus controlled, thus engaging learners' previous knowledge structures (e.g., Di Vesta & Peverly, 1984; Mayer, 1974). Another reason may be that a learner engaged in abstracting encounters and must deal with choice-points about how much and in what directions to abstract and may take more than one path at some of those choice points. In contrast, an

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

instructor or text serving up "ready-made" abstractions typically offers but a single path.

Research by Gick and Holyoak (e.g., 1983) addressed these issues. Gick (1985) gave subjects an initial story to serve as an analogue for the solution of a subsequent one. Subjects received also a diagram that abstractly summarized the solution to the first problem. Relative to the findings in preceding studies, serving subjects with ready-made abstractions facilitated transfer to the new problem. However, probably because the abstract diagram was provided ready made, much more transfer was obtained when subjects were cued as to the relevance of the first story to the solution of the second. In other studies of this kind (Gick & Holyoak, 1983), subjects were given two initial stories and were asked to write summaries of how the stories resembled each other. The writing of such summaries is a fine example of how mindful abstraction can be achieved. Not only did impressive transfer result in these studies, but also the percentage of subjects transferring the principles of the solution to the new story was highly correlated with the abstract quality of summaries: Ninety-one percent of the subjects writing high-quality summaries showed transfer without additional cueing versus only 30% of those who wrote poor ones.

What Transfers by Way of the High Road?

The high road to transfer comes into play during explicit instruction aimed at provoking or conveying well-understood abstractions. It also operates when automatic applications by way of the low road are thwarted or blocked, setting off epistemic processes. Belmont, Butterfield, and Ferretti (1982), for example, reviewed a number of efforts to teach retardates mnemonic and other strategies. They noted a number of failures of transfer and emphasized that, in six of seven experiments where transfer did occur, skills of mindful attention to and management of one's own processes were taught along with the strategies themselves. In another, particularly successful example, retardates practiced strategies on a list learning problem and, 1 year later, exhibited transfer to a prose recall problem (Brown & Barclay, 1976; Brown, Campione, & Day, 1981). These studies attest to the important role played by metacognitions, the guide—as we noted before—of mindful behavior.

The main distinction of the high road to transfer is the mindful generation of an abstraction during learning and its later application to a new problem or situation from which basic elements are similarly abstracted. The learner can rather easily retrieve the abstracted units while working in another context, because they have been abstracted to the extent that they already subsume the new context. Thus, while working on a physics problem, a student might remember a relevant technique from

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

calculus because the student—typically with the help of the text—encoded it in a very general way, with very general conditions of evocation. But there are other variants to the high road to transfer. For one such variant, a learner who already has interest in a particular area of application may abstract behavior and cognitions acquired in one context in the direction of the target context (forward reaching). For instance, the student specializing in physics may constantly be pondering physics applications while studying calculus.

In still another variant, high-road transfer begins in the transfer context rather than in the initial learning context. The individual abstracts from the transfer context certain characteristics of the problem at hand that allow interrogating, in a focused way, previous experience in other contexts. For instance, perhaps our physics student does not spontaneously think of a resource from calculus. But, pondering the physics problem, the student abstracts some general solution requirements from it and asks, "Do I know anything from calculus that might address this?" Reviewing calculus mentally (backward reaching), the student eventually turns up something.

It is also worth noting that high-road transfer may be evoked by metaphorical as well as literal matches between the learning context and the application context. The history of science and technology includes a number of episodes in which individuals noticed an analogy and developed it into an invention or a theory. For example, Gutenberg hit on the notion of a press for printing while attending a wine festival and observing the wine press (Koestler, 1964). Darwin arrived at the theory of natural selection while reading Malthus's *Essay on Population* and contemplating the survival pressures an exponentially expanding population would create (Darwin, 1911).

Qualitative Predictions

Unlike low-road transfer, the mechanism of high-road transfer predicts distant transfer through greater abstraction. The higher the abstraction, the greater the range of instances it subsumes and, consequently, the greater the range to which it might be applied. A case in point is a recent study carried out by Eva Guterman, a graduate student at the Tel Aviv University. In that study, seventh graders were taught to generate and apply abstract metacognitions to guide their reading of novel texts. A control group learned to ask content-specific questions while reading. Subjects in both groups manifested improved reading comprehension. However, whereas students in the abstract metacognition group showed substantial transfer effects to the activity of writing, measured 1 month later, subjects in the content-specific questions group showed no improvement in essay writing.

Higher abstraction does not, however, foster a greater amount of transfer

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

to a situation already within the range of the initial abstraction. That is, mindful abstraction may facilitate far reaching transfer at the expense of relatively poor learning of the original material, because the greater level of generality makes it harder to connect the representation to any given particular. For example, when studying the impact of providing a general mental model of the computer on learning, Mayer (1981) found that, under the model condition, subjects exhibited markedly better performance on programming tasks somewhat different from those used in the instruction, but slightly worse performance on tasks very much like the training tasks. Apparently, the mental model led students to develop general solution strategies while affording less specific help with the training tasks.

Another prediction concerns the symbol system in which the learning is cast. If transfer via the high road requires the reformulation of learned materials in a symbol system affording abstraction, then verbal learning should yield more transfer than learning in a symbol system that requires further translation into an abstraction-affording system. For instance, it follows from Olson and Bialystock (1983) that perceptual experience accompanied by a verbal narration should—if mindfully processed—facilitate transfer more than if accompanied by, say, pictorials, although the latter might be better for immediate mastery of the material.

The Roads Together

What about the relation between the two roads to transfer? Must they be traveled separately? Broadly speaking, each caters to somewhat different sorts of behavior and cognition, as already discussed. But, despite these trends, the two mechanisms are logically consistent. Both roads can be traveled at once—one certainly can both reflect on a behavior and practice it. Furthermore, what we do and do not reflect on is not just a consequence of ability but of what language and custom afford. By making an effort and constructing a vocabulary, one certainly can examine, for instance, motor skills, attitudes, or cognitive styles. In such cases, the practice would still work to limit the range of application were it not for the strong component of abstraction. This is precisely the advantage of teaching people to think about an activity they usually perform mindlessly, as pointed out by Langer (1989); not only does their performance improve but they also become able to apply the same learning to entirely new situations.

In general, we should not be surprised to find the two mechanisms working together from time to time. Chess experts, for example, depend on a repertoire of configurations of play accumulated by years of practice; at the same time, however, that repertoire fuels a very mindful process of strategic thinking as the chess master handles a particular game. Some of the master's strategic deliberations surely make their way into the master's

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

repertoire as deliberate abstractions which, on the other hand, themselves eventually become routinized if they withstand the test of repeated success. So, in a complex and mindful activity, such as chess play, we see the mechanisms working hand in hand.

SOME PUZZLES ABOUT TRANSFER EXAMINED

As noted in the introduction, sometimes expected transfer does not occur. Such puzzling instances have in part inspired the present resurgence of interest in transfer. Here we examine three such cases and explain the failure of transfer in terms of the high and low roads.

Failure of Transfer From Literacy

Scribner and Cole (1981) provided one relevant case in their study of the cognitive effects of literacy without schooling in the Liberian tribe of the Vai. This case has some importance because lay people and scholars alike commonly expect far and wide transfer from literacy. If literacy shapes culture, then it shapes the mind—that is the way literates come to think. Literacy presumably forces decontextualization of messages and so develops abstract thought processes. Others have argued that literacy leads to the mastery of the logical functions of language, thereby cultivating transferrable logical abilities (e.g., Olson, 1978). But the evidence concerning the effects of literacy was always confounded with the effects of schooling.

The Vai, however, had a written language but no schooling, thus providing a unique opportunity to study the one without the other. When Scribner and Cole took this opportunity, they found little evidence for transfer. The major influences of Vai literacy were limited to cognitive tasks designed by Scribner and Cole "to mirror a specific literacy practice." Influences on remote or general-ability tasks were spotty and, interestingly enough, often limited to experts who taught the Vai script. These findings were generally replicated with Arabic literacy, which also occurs within the Vai culture. Again, the cognitive advantages of the literates were few and narrow in scope. The scanty stronger effects appeared only in individuals who understood Arabic and taught it. In general, with the exception of one transfer task (sorting), neither Vai nor Arabic literacy affected performance on tasks that tap higher order or metalinguistic skills.

The failure of transfer, observed by Scribner and Cole, should not surprise us in light of the present theory of transfer. As the authors themselves pointed out, the literacy practices afforded by the daily life of the Vai are very limited when compared to those in more modern cultures

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

which are more oriented to text and technology. Indeed, the Vai literacy is not a necessary or even very important part of one's functioning in the Vai society. Nothing crucial depends on its mastery, and nothing new has been introduced into the Vai culture by means of it. Accordingly, the cognitive skills involved in Vai literacy are practiced only within a narrow range of repeated situations and hardly ever invoked and exercised in others. In other words, a situation of extensive but not varied practice prevails, failing to meeting the necessary conditions of low-road transfer. Literacy that resembles more a hobby than a culturally central activity does not provide sufficient practice in sufficiently varied contexts to facilitate the cultivation of mental skills that can be applicable to new instances.

The high road, which could lead to broader transfer by means of abstraction rather than diverse practice, sees little use among the Vai either. There is nothing in the Vai culture and daily life that compels one to take it, save perhaps if one is teaching it. Teachers often have to generate rules that, even if not taught directly to others, guide their own instructional tactics. Indeed, stronger cognitive effects were found among teachers, suggesting some high-road transfer.

Transfer From Computer Programming

As with literacy, computer programming often is seen as a mind shaper, a cultivator of higher order cognitive skills, such as rigorous thinking, mathematical problem solving, and thinking about thinking (e.g., Feurzeig et al., 1971; Feurzeig, Papert, Bloom, Grant, & Solomon, 1969; Papert, 1980; Salomon & Perkins, 1987). In recent years, spurred by hopes of substantial cognitive impact, a number of investigators have carried out studies examining the cognitive abilities of students who had received programming instruction. The results have been largely negative, but with occasional positive findings. Can the present model of transfer account for both the negative and positive results, explicating under what conditions transfer from programming can be expected?

First, we examine some of the negative results. In several studies carried out with children receiving 50 hr of programming practice in LOGO, no serious traces of transfer to activities, such as planning in advance or goal evaluation outside of a programming context, were found, even though such skills are important in programming (Pea & Kurland, 1984). In a study of BASIC, where high school students received 2 years of general instruction in computer literacy, including BASIC, no substantial transfer effects appeared (Kurland, Pea, Clement, & Mawby, 1986). In a study of first-semester BASIC in high school students, where the investigators succeeded in improving substantially the programming performance of the treatment group through materials that provided the students with better mental

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

models and strategies for programming, again no transfer effects appeared (Perkins, Schwartz, & Simmons, in press). Other studies in which the students had significantly more programming practice have yielded somewhat more encouraging results, yet none sufficiently strong enough to show that programming has the broad transfer effects expected (e.g., Howe, O'Shea, & Plane, 1979; Ross & Howe, 1981).

One obvious reason for failure of transfer in short-term studies is the poor level of programming attained. A prerequisite for either low- or high-road transfer is, of course, initial learning. Pea and Kurland (1984) noted that the 50 hr of nondirective instruction involved in their studies did not lead to much planning or sophistication of any sort, even within the programming context, so it is hardly surprising that no transfer occurred. However, simple failure to develop adequate mastery to warrant transfer may not be the whole story. Note that the study by Kurland et al. (1986) still found no substantial transfer after 2 years of BASIC and that Perkins et al. (in press) found none, even from a treatment that enhanced BASIC performance itself.

What else might limit transfer in these contexts besides simply minimal mastery of the subject matter itself? First of all, practice is rather limited in quantity, a far cry from what the low road to transfer would require. Fifty hours or even a 2-year course do not come close to attaining the near-automaticity required. Second, whatever practice occurs, happens within the context of programming instruction itself; the condition for far low-road transfer of extensive varied practice, which stretches the skill beyond its original context of learning, plainly is not met. High-road transfer, the other recourse, depends on an instructional style that either provokes students to abstract mindfully from the programming context principles of greater scope or explicitly provides such principles and assures that students thoroughly understand them in their greater scope. It is plain that most programming instruction does no such thing. Nor, indeed, have most of those who have spoken for the potential impact of programming on cognitive skills suggested that such explicit attention would be necessary.

However, several recent efforts to obtain transfer from programming have, in various ways, promoted mindful abstraction. Clements (1985a, 1985b) and Clements and Gullo (1984) reported significant gains from a few weeks of LOGO on measures of ideational fluency, metacognitive use, and cognitive style with different groups of students who enjoyed high-level guidance from teaching assistants, a high-road element in the teaching situation (Clements & Gullo, 1984). Carver and Klahr (1987) designed a LOGO intervention that focused on debugging and quite explicitly taught a debugging strategy with emphasis on its general applicability. They obtained substantial learning and transfer of the debugging strategy.

In summary, current findings follow that one would expect from the

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

model of transfer discussed here: The instruction cannot be expected to meet the conditions for low-road transfer; when it meets the conditions for high-road transfer, transfer is typically found.

Inert Knowledge as a Problem of Transfer

Yet another puzzle about transfer concerns the failure of near or even "very near" transfer in cases where, one would think, there should be no question of a shortfall. Several investigations in the experimental literature have demonstrated this sort of problem. For example, Asch (1969) reported a study in which subjects learned a set of paired associates well and, immediately thereafter, learned another list of paired associates that, unbeknownst to them, included one pair that also occurred on the first list. The prediction might be that the already learned pair on the second list would be "relearned" instantly. However, the results were quite different. Many of the subjects showed no savings whatsoever in learning the supposedly familiar pair. Others mastered it instantly. Probes disclosed that only those subjects that recognized the pair as familiar showed savings. However, once subjects were told that there might be an old pair on the new list, they deliberately searched for it, found it, and all showed perfect savings. Asch argued from this pattern of findings that recognition was a key element in retrieval; without an access route to well-learned information, the information might as well not be there.

Experiments conducted by Bransford and his colleagues (e.g., Bransford, Sherwood, Vye, & Reiser, 1986) have demonstrated similar phenomena both with certain kinds of riddles and with subject-matter content. For example, subjects, who were told a few minutes before that the initial score in any baseball game is 0 to 0, were asked to explain the miraculous feat of a psychic who can give the score of any baseball game before it begins. The subjects often failed to see the point, despite the recency of the crucial information. However, once alerted to the possibility that information they had recently encountered might be applicable, nearly all subjects solved the riddles. Findings in the same vein have also been reported by Gick and Holyoak (1983).

Similar results for more conventional subject-matter learning have been reported by Bransford and his co-workers (Bransford, 1987), who also investigated, in some detail, the learning conditions under which information was retrieved and used appropriately. They concluded that only when the acquisition process involved active use of the information in a problem-solving manner relevant to the later context of use did the information prove active rather than inert. In one instructional experiment, for example, they presented several kinds of science information conventionally for a control group; a treatment group received the information in a format

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

where the learners used the information to conduct actively a variety of problem-solving activities in connection with the first few minutes of *Raiders of the Lost Ark*. These served as an organizing context. On a later problem-solver task that invited analogous use of the information, treatment students showed far more use of it than did control students. Similar sorts of "problem-based learning" have also seen effective use in contexts of medical education in which the concern is that student physicians will develop a technical knowledge base in physiology and anatomy that hardly informs at all their diagnostic practices (Barrows & Tamblyn, 1980).

These findings about inert knowledge amount to results about near transfer: Information acquired in one context fails to impact on another to which it is straightforwardly and immediately relevant. How can one account for the failures and successes of transfer in terms of the present model? Straightforward presentation of information satisfies the conditions neither for low-road nor for high-road transfer. Regarding the low road, there is no varied practice, indeed no practice at all, of active applications of the information—the desired target performance. Regarding the high road, during learning there is no provocation promoting mindfulness or extraction of the abstract significance of the information. To be sure, a few learners exhibit active use of the information anyway; but naturally some students have habits of practice and mindful abstraction that they project on situations even when such behavior is not provoked. Indeed, this is part of what it means to be a good student. Hence, the inert knowledge findings are entirely in keeping with the present framework.

Another feature of these studies is the strong effect of cueing subjects to try to apply information they recently encountered. This characteristic also accords with the low-road–high-road model. Essentially, cueing induces a search through recently obtained information for relevant connections. That is, it triggers backward-reaching transfer, one of two varieties of high-road transfer discussed earlier.

Finally, why does an active treatment of the information in the first place promote its later active use? Both the low road and the high road would seem to contribute here. First of all, because active use of the information in a problem-solving manner is the target performance, similar use in the learning context sets up conditions for stimulus and response generalization according to the low road. Of course, extensive varied practice is needed for greater amounts of low-road transfer, but in such cases as this, the learning and target contexts may be close enough so that a few trials suffice. Second, the emphasis during learning on problem solving, with a further boost from involving stimuli such as *Raiders of the Lost Ark,* alerts the learner, providing a high level of mindfulness and thereby promoting forward-reaching high-road transfer. Any discussion of general principles or mul-

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

tiple examples exercising the same principle would specifically provoke abstraction, as in Gick and Holyoak's (1983) studies reviewed earlier.

The present model of transfer also points to an instructional opportunity neglected in the research on inert knowledge reviewed here. The remedies investigated all involved promoting low-road transfer and forward-reaching high-road transfer. Yet, as the positive effects of cueing showed, backward-reaching high-road transfer also is an option—if one could teach learners to cue themselves to undertake the kinds of searches needed. Admittedly, the cues typically used in these experiments did not just encourage subjects to think back on what they knew, but directed their attention to the information just presented. Nonetheless, one would expect some effects if students learned to conduct generally an active search of recently acquired knowledge (which, in academic contexts, generally is relevant to what one is doing at the moment) and knowledge acquired earlier that shows earmarks of relevance. This, of course, requires mindfully abstracting from the task at hand those general features that point to the sort of knowledge that would be useful. In summary, the present model argues that learning experiences that establish the conditions for low-road and forward-reaching high-road transfer plus problem-solving habits that emphasize backward-reaching high-road transfer would yield the most active use of knowledge that otherwise will lie inert.

Taken together, the three examples of failure to find transfer illustrate how casual judgments, as to what will yield transfer and what will not, yield unreliable predictions. It seems plausible that such demanding cognitive activities as reading, writing, and computer programming would routinely have cognitive ripple effects. After all, each exercises the mind in a substantial way. Likewise, it would seem that knowledge rather directly applicable to a problem and recently acquired or alerted would be straightforwardly applied. All these judgments amount to assessments that the cognitive element previously acquired is relevant to the hoped-for transfer performance; relevance is treated as a sufficient condition for transfer. The essence of the negative findings reviewed is that relevance is a necessary but not sufficient condition. In particular, we argue that, unless the conditions for low- or high-road transfer are met, transfer will not occur no matter how relevant the previous learning. Failure to recognize this point leads to false expectations about the benefits of a variety of learning experiences in schools and out of them.

The Prospects of Teaching for Transfer

The analysis undertaken here, while dashing some hopes, concurrently discloses untapped opportunities. The explanation of failure of transfer

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

from programming carries with it a recipe for doing better, one already evinced in the few cases of positive far transfer from programming. The examination of inert knowledge points not only to the documented potential for establishing active knowledge by instruction that fosters forward-reaching transfer, but also to the possibility, in the same contexts, of harvesting even more transfer by emphasizing techniques of backward-reaching transfer that learners can employ to make the most of available knowledge.

Imagine, for example, a history teacher wanting his or her students to develop a historical perspective on contemporary events. Uninformed about the difficulties of transfer, the history teacher might presume that students would spontaneously make some illuminating connections and might be puzzled when, for the most part, they do not. However, the conditions for transfer discussed here write a rough recipe for how the history teacher might do better—by teaching for transfer explicitly.

What might the history teacher do? Low-road transfer does not appear to be a good route, because students are not likely to become thoroughly versed in the knowledge in question. But the teacher might teach for forward reaching high-road transfer. The teacher could decontextualize causal factors and important patterns in history, describing specific cases, like the French Revolution, in terms of the general forces at work and highlight how the same general forces figure in other periods of history as well. Better yet, the teacher could encourage the students to try to abstract for themselves some common principles. What is the same and what is different, for example, about the French and the Iranian Revolutions, and what consequences might the similarities and contrasts have? What are the similarities and differences between monarchs and dictators the students have studied, and what might the general consequences be?

Most pointedly of all, the history teacher can introduce direct discussions of contemporary events. To provoke forward-reaching transfer, the teacher can select an episode in history and encourage students to seek contemporary analogs. To provoke backward-reaching transfer, the teacher can choose a current phenomenon (e.g., Gorbachov's celebration and promulgation of "glasnost") and urge students to reach into their historical repertoires for analogies and disanalogies. The payoff of such activities, of course, is not just particular transfers made but the establishment of an expectation for transfer. The students learn that such connection making is part of what it is to think historically. The same tale can be told for any subject.

In sum, we believe that the perspective outlined here has very encouraging implications for the prospects of teaching for transfer. Although the conditions for low-road transfer will often be difficult to arrange in classroom settings, the conditions for high-road transfer can be fairly

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

straightforwardly engineered. Although transfer may not typically occur in classroom settings on its own, there is every reason to believe that it can be encouraged. If only we teach it, we are most likely to get it.

TAKING STOCK: WHAT A MODEL OF TRANSFER CAN EXPLAIN

We presented a perspective on transfer of learning, discussed its qualitative predictions and a number of findings consistent with those predictions, and showed how it explains certain failures of transfer in the literature. At this point, it makes sense to take stock of the model of transfer outlined here. What does it attempt? Why does it not address certain objectives that might seem important for a theory of transfer? What fresh illuminations does it offer regarding the phenomena of transfer?

Broadly speaking, the present view of transfer addresses mainly how transfer occurs, identifying and elaborating the distinctive low and high road mechanisms. The model deals much less with what transfers to what. To be sure, one might like a theory of transfer that allowed fine-grained predictions regarding the "whats" of transfer. For instance, one might ask of such a theory whether effective instruction in formal logic would enhance the learning of physics or whether learning to ride a bicycle would make it easier to learn to drive a car. However, we suggest that predicting what will transfer to what is far too much to ask of a theory of transfer specifically. Indeed, preoccupation with this problem may have somewhat misdirected prior research in the field.

The key point is that what transfers to what necessarily calls for an analysis of the constituents of the "whats." For instance, the potential for studies in formal logic transferring to physics will depend on what component skills, key conceptual structures, pivotal procedures, or elements in some other sense of formal logic might contribute to physics. Such an analysis plainly calls for a theory of the sorts of components that contribute to cognitive processing in general and in particular cases; it demands an encompassing theory of cognitive functioning, not just a theory of transfer per se. An advantage of the model of transfer offered here is that it factors out the "how" question from the far larger "what" questions.

Another classical effort to deal with the "what transfers to what" question invokes the notion of "distance" between performances or contexts of performance. One might want a theory of transfer that provides a good distance metric, from which predictions of degree of transfer could be made. However, we suggest that expectation also is misguided. First of all, while using the concept of distance informally, we already pointed out its potential circularity: People's similarity judgments of contexts or perfor-

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

mances are likely to be influenced by what sorts of transfers are commonplace. Second, a well-developed theory of distance would call for a theory-based analysis of the particular respects in which two performances resembled one another, which requires an analysis of their constituents, returning us to the need for an encompassing theory of cognitive functioning already mentioned. Third, high-road transfer is a highly constructive act of mind; it seems doubtful that one could produce a metric that reliably forecast the connections people would invent in achieving far high-road transfer.

Fourth and finally, there is a formal objection to the quest for a distance metric: Transfer relations do not obey some elementary requirements for a proper metric. Sometimes practice on A trains B better than does practice on B itself; but B must be closer to B than A. Sometimes practice on A trains B better than equivalent practice on B trains A. But A is no further from B than B is from A. There is plentiful empirical evidence for both these anomalies of transfer (Kolers & Roediger, 1984). For instance, in laboratory experiments on the perceptuomotor task of reading transformed text—text with letters inverted, reflected, or modified in like ways—substantial asymmetries of transfer appear, and sometimes one transformation trains another better than the other trains itself (Kolers & Perkins, 1975). Salomon and Sieber-Suppes (1972) found that training subjects to become better cue attenders improved their ability to generate multiple hypotheses, but not the other way around.

As to transfer doing better than practice on the target performance itself, we often learn something better by first learning a metaphor for it than by attempting to learn it directly (Gick & Holyoak, 1983; Johnson-Laird, 1983). Asymmetries of transfer often arise because A is a better model for B than B is for A (Tversky, 1977). Understanding a switchboard certainly informs one's understanding of human communications more than understanding human communications informs one's understanding of a switchboard. In summary, although a distance metric is an attractive desideratum at first sight, analysis of the requirements for such a metric shows that it is not really a feasible or particularly desirable feature of a theory of transfer.

Recognizing that "what transfers to what" across what distance is not the right question for someone studying a theory of transfer in itself to ask, we offer instead an analysis of the "hows" of transfer—the high- and low-road transfer mechanisms and the broad conditions under which each will yield transfer. So far as we know, the separate mechanisms of low-road and high-road transfer have not been distinguished before in the literature. As already discussed, taking both into account helps to explain some puzzling phenomena of transfer.

But more than that, the two roads open up a new approach to analyzing potential occasions of transfer, one complementary to most previous

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

inquiries. In support of this, we conclude by highlighting how much richer the questions are that one would ask in examining a context of potential transfer with the low and high roads in mind. Conventional questions would be as follows: What elements of the first performance might equip one to handle better the second? How does degree of practice or understanding of the initial performance impact on transfer to the second?

These are appropriate queries, but, given a specific situation in which transfer might or might not occur, we would add questions like the following: Concerning the high road, in the conditions of learning, what promotes mindfulness and, in particular, encourages abstraction? Under circumstances of potential application, what provokes mindfulness in general and encourages reaching back for potentially applicable elements from prior learning? What metacognitive habits does the person bring to the occasion that would abet high-road transfer? Concerning the low road, is the practice sufficient to yield automatization? Is the practice varied enough to sample widely the domain to which transfer is sought? Concerning both roads, whatever analysis of the performance in question you have, on that analysis does the performance lend itself to low-road or high-road transfer, both in different ways, or what? We suggest that these questions and others like them often can be answered and that the answers illuminate the nature and prospects of transfer.

ACKNOWLEDGMENTS

First authorship was determined by the flip of a coin.

We gratefully acknowledge support from the Spenser Foundation to Gavriel Salomon and the Office of Educational Research and Improvement (Contract #OERI 400-83-0041) to the Educational Technology Center at the Harvard Graduate School of Education.

The views expressed here do not necessarily reflect the position or policy of the supporting agencies.

REFERENCES

Asch, S. E. (1969). A reformulation of the problem of associations. *American Psychologist, 24,* 92–102.

Bandura, A., & Cervone, M. (1986). Differential engagement of self-reactive influences in cognitive motivation. *Organizational Behavior and Human Decision Processes, 38,* 92–113.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education.* New York: Springer.

Belmont, J. M., Butterfield, E. C., & Ferretti, R. P. (1982). To secure transfer of training instruct self-management skills. In D. K. Detterman & R. J. Sternberg (Eds.), *How and how*

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

much can intelligence be increased? (pp. 147–154). Norwood, NJ: Ablex.

Bransford, J. D. (1987). *Enhancing thinking and learning.* San Francisco: Freeman.

Bransford, J. D., Franks, J. J., Vye, N. J., & Sherwood, R. D. (1986, June). *New approaches to instruction: Because wisdom can't be told.* Paper presented at the Conference on Similarity and Analogy, University of Illinois, Urbana.

Bransford, J. D., Sherwood, R., Vye, N., & Reiser, J. (1986). Teaching thinking and problem-solving. *American Psychologist, 41,* 1078–1089.

Brown, A. L. (1975). The development of memory: Knowing knowing about knowing, and knowing how to know. In H. W. Reese (Ed.), *Advances in child development and behavior* (Vol. 10, pp. 103–152). New York: Academic.

Brown, A. L., & Barclay, C. R. (1976). The effects of training specific mnemonics on the metamnemonic efficiency of retarded children. *Child Development, 47,* 70–80.

Brown, A. L., Bransford, J. D., Ferrara, R. A., & Campione, J. C. (1983). Learning, remembering and understanding. In J. H. Flavell & E. M. Markman (Eds.), *Carmichael handbook of child psychology* (Vol. 3, pp. 515–529). New York: Wiley.

Brown, A. L., Campione, J. C., & Day, J. D. (1981). Learning to learn: On training students to learn from texts. *Educational Researcher, 10,* 14–21.

Carver, S. M., & Klahr, D. (April, 1987). *Analysis, instruction, and transfer of the components of debugging skill.* Paper presented at the biennial meeting of the Society for Research in Child Development, Baltimore, MD.

Chase, W. C., & Simon, H. A. (1973). Perception in chess. *Cognitive Psychology, 4,* 55–81.

Chi, M. T. H., Glaser, R., & Rees, E. (1982). Expertise in problem solving. In R. Sternberg (Ed.), *Advances in the psychology of human intelligence* (pp. 7–75). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Clements, D. H. (1985a, April). *Effects of Logo programming on cognition, metacognitive skills, and achievement.* Paper presented at the meeting of the American Educational Research Association, Chicago, IL.

Clements, D. H. (1985b). Research on Logo in education: Is the turtle slow but steady, or not even in the race? *Computers in the Schools, 2,* 55–71.

Clements, D. H., & Gullo, D. F. (1984). Effects of computer programming on young children's cognition. *Journal of Educational Psychology, 76,* 1051–1058.

Darwin, F. (Ed.). (1911). *The life and letters of Charles Darwin, Vol. 1.* New York: Appleton.

Di Vesta, F. J., & Peverly, S. T. (1984). The effects of encoding variability, processing activity, and rule-example sequence on the transfer of conceptual rules. *Journal of Educational Psychology, 76,* 108–119.

Eagly, A. H. (1983). Gender and social influence: A social psychology analysis. *American Psychologist, 38,* 971–981.

Feurzeig, W., Lukas, G., Faflick, P., Grant, R., Lukas, J., Morgan, R., Weiner, W., & Wexelblat, P. (1971). *Programming languages as a conceptual framework for teaching mathematics* (BBN Report No. 2165). Cambridge, MA: Bolt, Beranek, and Newman.

Feurzeig, W., Papert, S., Bloom, M., Grant, R., & Solomon, C. (1969). *Programming languages as a conceptual framework for teaching mathematics* (BBN Report No. 1889). Cambridge, MA: Bolt, Beranek, and Newman.

Fisk, A. D., & Schneider, W. (1984). Memory as a function of attention, level of processing, and automatization. *Journal of Experimental Psychology: Learning, Memory and Cognition, 10,* 187–197.

Gardner, H. (1983). *Frames of mind.* New York: Basic Books.

Gick, M. L. (1985). The effect of a diagram retrieval cue on spontaneous analogical transfer. *Canadian Journal of Psychology, 39,* 460–466.

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive Psychology, 15,* 1–38.

Gick, M. L., & Holyoak, K. J. (1987). The cognitive basis for knowledge transfer. In S. M.

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

Cromier & J. D. Hagman (Eds.), *Transfer of learning* (pp. 9–47). New York: Academic.
Goodman, N. (1978). *Ways of worldmaking.* Indianapolis: Hackett.
Greenfield, P. M. (1984). *Mind and media.* Cambridge, MA: Harvard University Press.
Hayes-Roth, B. (1977). Evolution of cognitive structure and processes. *Psychological Review, 84,* 260–278.
Howe, J. A. M., O'Shea, T., & Plane, F. (1979). Teaching mathematics through Logo programming: An evaluation study. In R. Lewis & D. Tagg (Eds.), *Computer-assisted learning: Scope, progress and limits* (pp. 241–253). Amsterdam, The Netherlands: North-Holland.
Johnson-Laird, P. N. (1983). *Mental models.* Cambridge, MA: Harvard University Press.
Kane, J. M., & Anderson, R. C. (1978). Depth of processing and inference effects in the learning and remembering of sentences. *Journal of Educational Psychology, 70,* 626–635.
Kellog, R. T. (1982). When can we introspect accurately about mental processes? *Memory & Cognition, 10,* 141–144.
Kerr, B. (1973). Processing demands during mental operations. *Memory & Cognition, 1,* 401–412.
Kintsch, W. (1977). *Memory and cognition.* New York: Wiley.
Koestler, A. (1964). *The act of creation.* New York: Dell.
Kolers, P. A. (1973). Remembering operations. *Memory & Cognition, 1,* 347–355.
Kolers, P. A. (1975). Memorial consequences of automatized encoding. *Journal of Experimental Psychology: Human Learning and Memory, 1,* 689–701.
Kolers, P. A., & Perkins, D. N. (1975). Spatial and ordinal components of form perception and literacy. *Cognitive Psychology, 7,* 228–267.
Kolers, P. A., & Roediger, H. L. (1984). Procedures of mind. *Journal of Verbal Learning and Verbal Behavior, 23,* 425–449.
Kurland, D. M., Pea, R. D., Clement, C., & Mawby, R. (1986). *A study of the development of programming ability and thinking skills in high school students.* New York: Bank Street College of Education, Center for Children and Technology.
Langer, E. J. (1985). Playing the middle against both ends: The influence of adult cognitive activity as a model for cognitive activity in childhood and old age. In S. R. Yussen (Ed.), *The development of reflection* (pp. 267–285). New York: Academic.
Langer, E. J. (1989). *Mindfulness.* Reading, MA: Addison-Wesley.
Langer, E. J., & Imber, L. E. (1979). When practice makes imperfect: Debilitating effects of overlearning. *Journal of Personality and Social Psychology, 37,* 2014–2024.
Mayer, R. E. (1974). Acquisition processes and resilience under varying testing conditions for structurally different problem-solving procedures. *Journal of Educational Psychology, 66,* 644–656.
Mayer, R. E. (1981). The psychology of how novices learn computer programming. *Computer Surveys, 13,* 121–141.
Mayer, R. E., & Greeno, J. G. (1972). Structural differences between learning outcomes produced by different instructional methods. *Journal of Educational Psychology, 63,* 165–173.
Miller, J. G. (1984). Culture and the development of everyday social explanation. *Journal of Personality and Social Psychology, 46,* 961–978.
Nickerson, R., Perkins, D. N., & Smith, E. (1985). *The teaching of thinking.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
Olson, D. R. (1978). The languages of instruction: On the literate bias of schooling. In R. C. Anderson, R. J. Spiro, & W. E. Montague (Eds.), *Schooling and the acquisition of knowledge* (pp. 65–89). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
Olson, D. R. (1980). In the language and authority of textbooks. *Journal of Communication, 30,* 186–196.
Olson, D. R., & Bialystock, E. (1983). *Spatial cognition.* Hillsdale, NJ: Lawrence Erlbaum

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013

Associates, Inc.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas.* New York: Basic Books.

Pascual-Leone, J. (1984). Attention, dialectic and mental effort: Toward an organismic theory of life stages. In M. L. Commons, F. A. Richards, & C. Armon (Eds.), *Beyond formal operations* (pp. 182–215). New York: Praeger.

Pea, R. D., & Kurland, D. M. (1984). On the cognitive effects of learning computer programming. *New Ideas in Psychology, 2,* 137–168.

Perkins, D., Schwartz, S., & Simmons, R. (in press). Instructional strategies for the problems of novice programmers. In R. Mayer (Ed.), *Teaching and learning computer programming: Multiple research perspectives.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Pressley, M. (1986). The relevance of the good strategy user to the teaching of mathematics. *Educational Psychologist, 21,* 139–162.

Ross, L. (1977). The intuitive psychologist and his shortcomings. In L. Berkowitz (Ed.), *Advances in experimental social psychology* (Vol. 10, pp. 173–220). New York: Academic.

Ross, P., & Howe, J. (1981). Teaching mathematics through programming: Ten years on. In R. Lewis & D. Tagg (Eds.), *Computers in education* (pp. 143–148). Amsterdam, The Netherlands: North-Holland.

Salomon, G. (1979). *Interaction of media, cognition and learning.* San Francisco: Jossey-Bass.

Salomon, G. (1983). The differential investment of mental effort in learning from different sources. *Educational Psychologist, 18,* 42–50.

Salomon, G., & Globerson, T. (1987). Skill is not enough: The role of mindfulness in learning and transfer. *International Journal of Research in Education, 11,* 623–638.

Salomon, G., & Perkins, D. N. (1987). Transfer from programming: When and how? *Journal of Educational Computing Research, 3,* 149–169.

Salomon, G., & Sieber-Suppes, J. (1972). Learning to generate subjective uncertainty. *Journal of Personality and Social Psychology, 23,* 163–174.

Schneider, W., & Fisk, D. (1984). Automatic category search and its transfer. *Journal of Experimental Psychology: Learning, Memory and Cognition, 10,* 1–15.

Scribner, S., & Cole, M. (1981). *The psychology of literacy.* Cambridge, MA: Harvard University Press.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84,* 127–190.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643–661.

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. *Psychological Review, 8,* 247–261.

Tversky, A. (1977). Features of similarity. *Psychological Review, 84,* 327–352.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Weinstein, C. E., & Mayer, R. E. (1985). The teaching of learning strategies. In M. C. Wittrock (Ed.), *Handbook of research on teaching* (3rd ed., pp. 315–327). New York: Macmillan.

Downloaded by [University of Illinois at Urbana-Champaign] at 12:18 31 May 2013